Snowmass Muon Collider Forum

Wednesday May 19, 2021, 5:00 PM → 7:05 PM Europe/Rome

Beam Induced Background Issues

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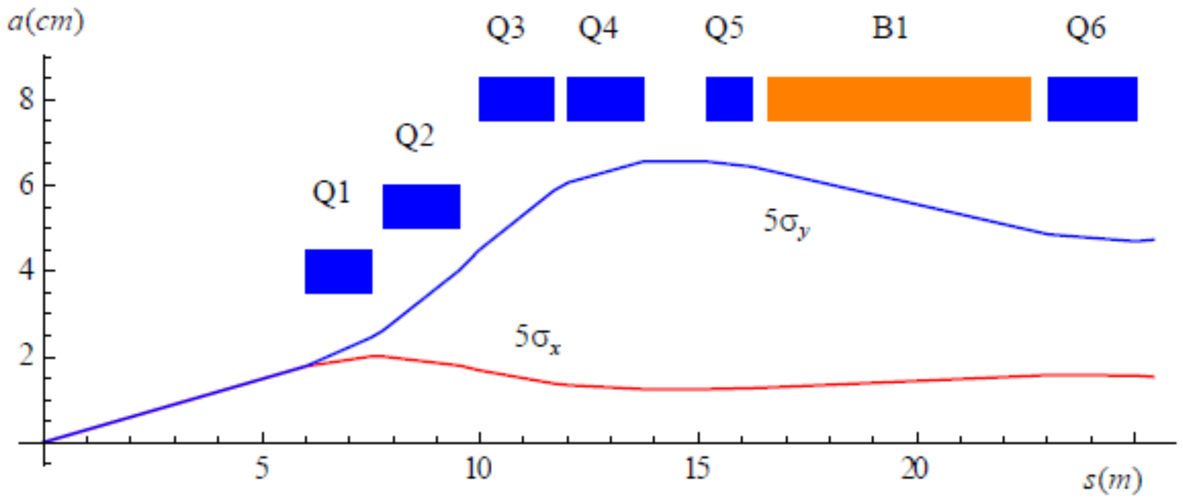
Optimization of Interaction Region at $\sqrt{s} = 1.5$ TeV

Y.I. Alexahin et al. *Muon Collider Interaction Region Design* FERMILAB-11-370-APC
N.V. Mokhov et al. *Muon collider interaction region and machine-detector interface design* Fermilab-Conf-11-094-A

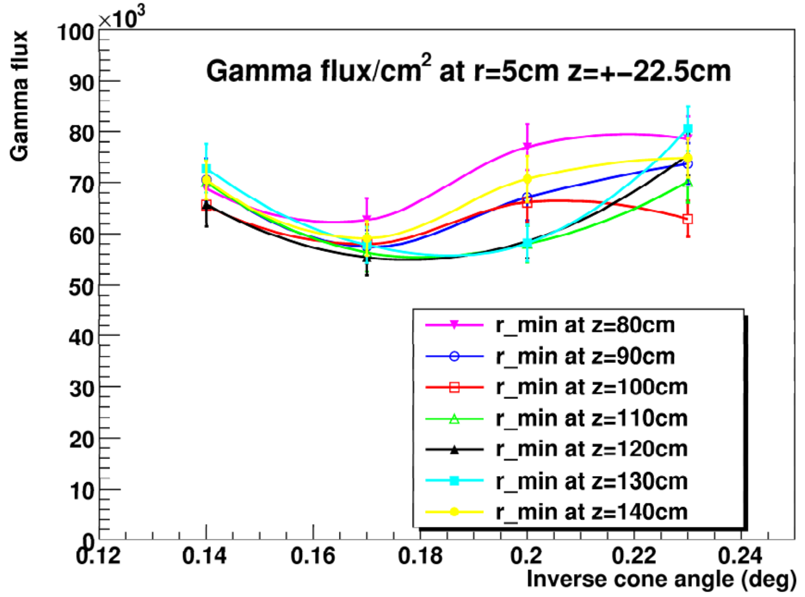
Parameter	**Unit**	**Value**
Beam energy	TeV	0.75
Repetition rate	Hz	15
Average luminosity / IP	10^{34}/cm^2/s	1.1
Number of IPs, N_{IP}	-	2
Circumference, C	km	2.73
β^*	cm	1 (0.5-2)
Momentum compaction, α_p	10^{-5}	-1.3
Normalized r.m.s. emittance, $\varepsilon_{\perp N}$	π·mm·mrad	25
Momentum spread, σ_p/p	%	0.1
Bunch length, σ_s	cm	1
Number of muons / bunch	10^{12}	2
Beam-beam parameter / IP, ξ	-	0.09
RF voltage at 800 MHz	MV	16



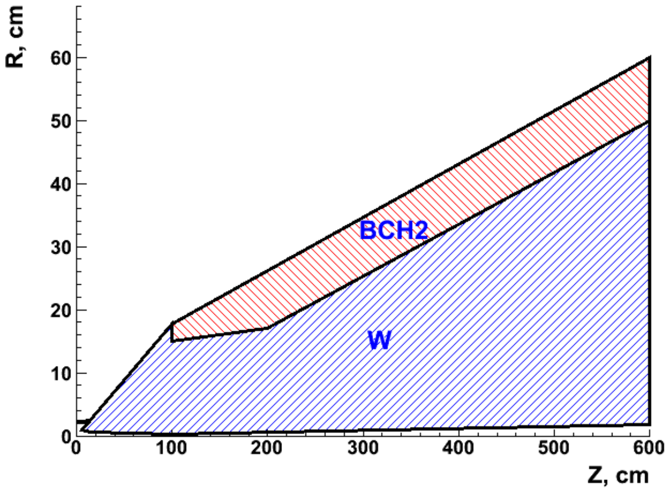
Quadrupoles in Nb_3Sn characteristics in the papers.
Dedicated dipoles to minimize the number of decay electrons in the coils and in the inner part of the detector.

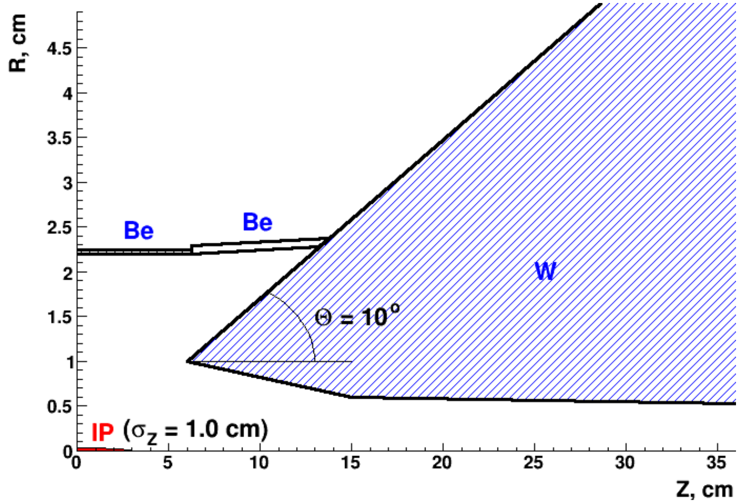
Detector Nozzle Optimization at $\sqrt{s} = 1.5$ TeV

For example, gamma flux as a function of the angle of inner cone opening towards IP at the outer cone angle of 10°



These studies have brought to the final nozzle configuration

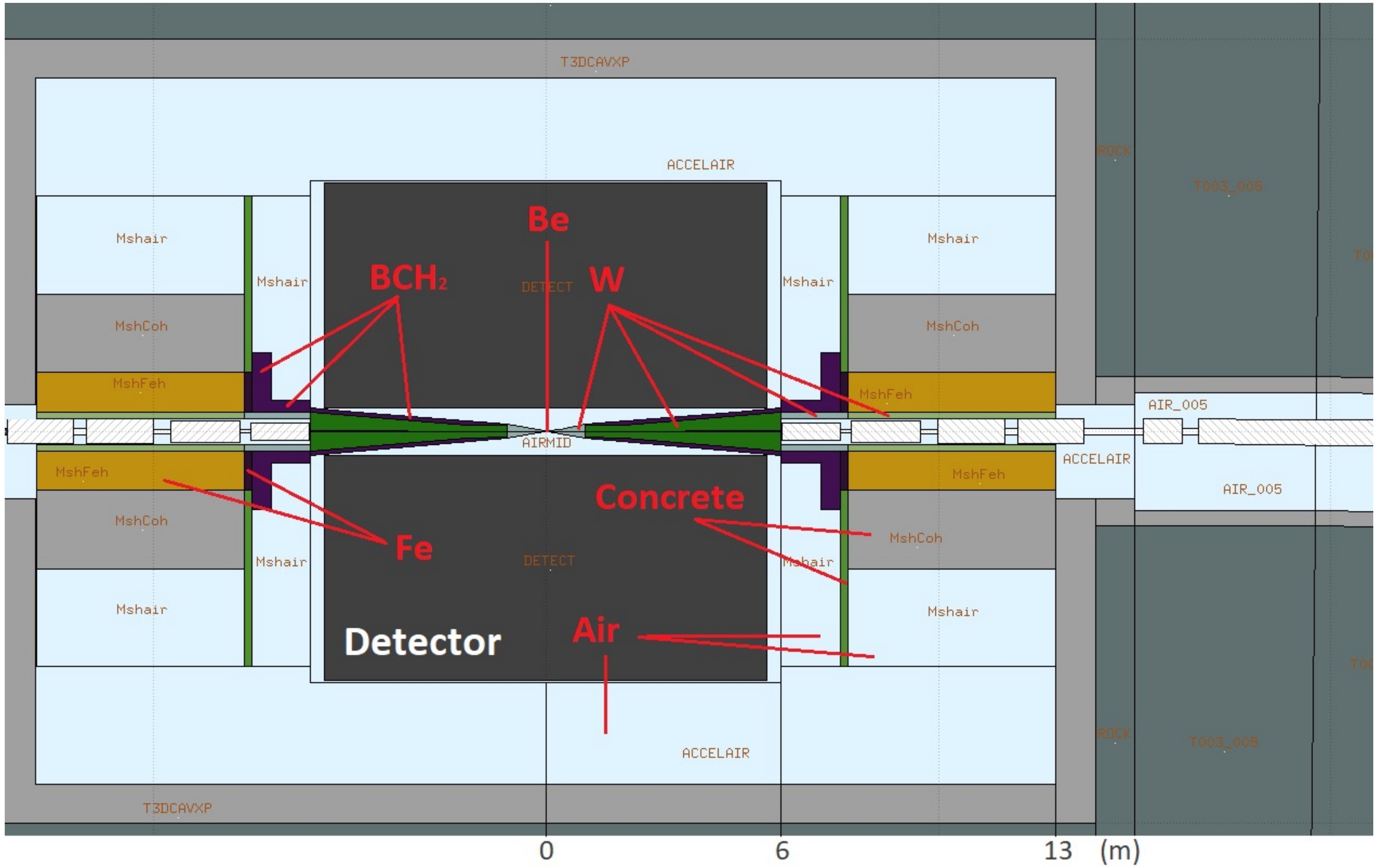




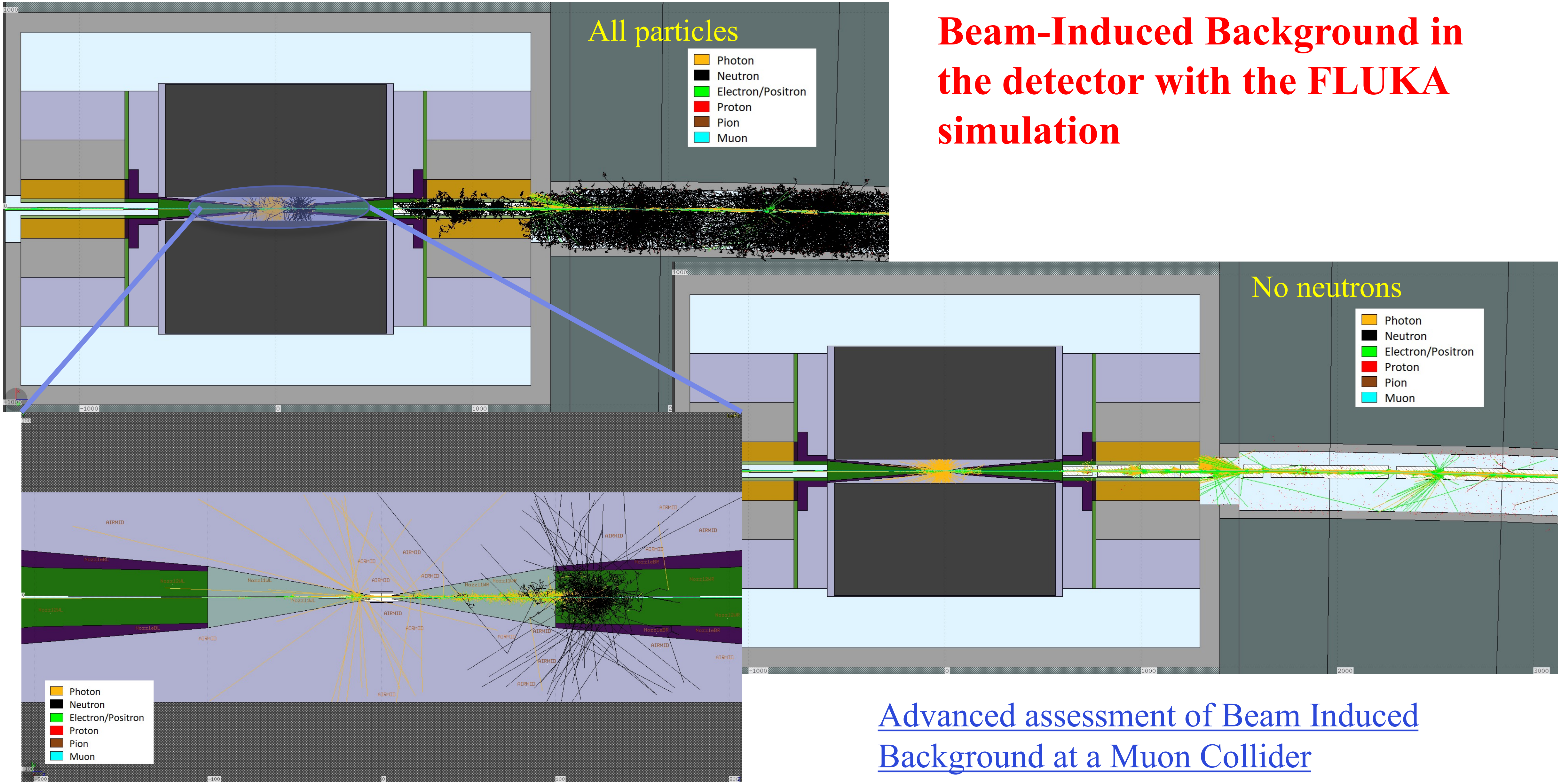
Di Benedetto et al., A study of muon collider background rejection criteria in silicon vertex and tracker detectors. Journal of Instrumentation13(2018)

Beam-Induced Background Generation

Machine lattice and optics, provided by MAP for $\sqrt{s} = 1.5$ TeV $\sqrt{s} = 3$ TeV, are used to generate the machine geometry, which is then used by FLUKA Monte Carlo to generate muon beams decays on the “detector envelop”

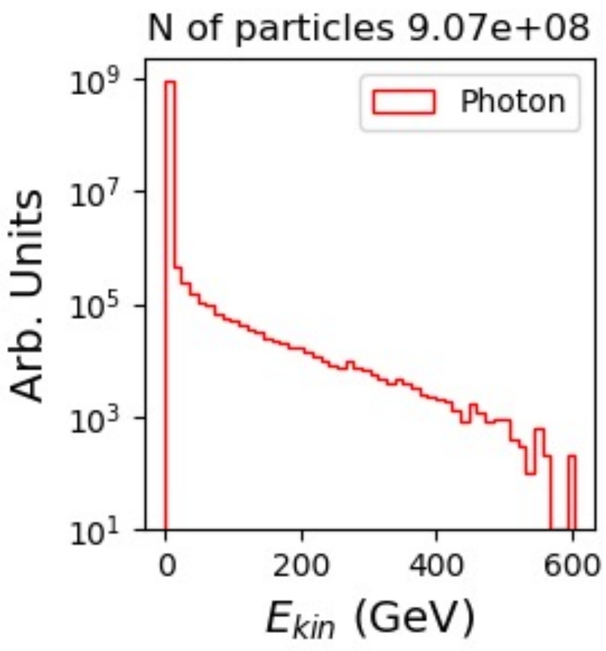


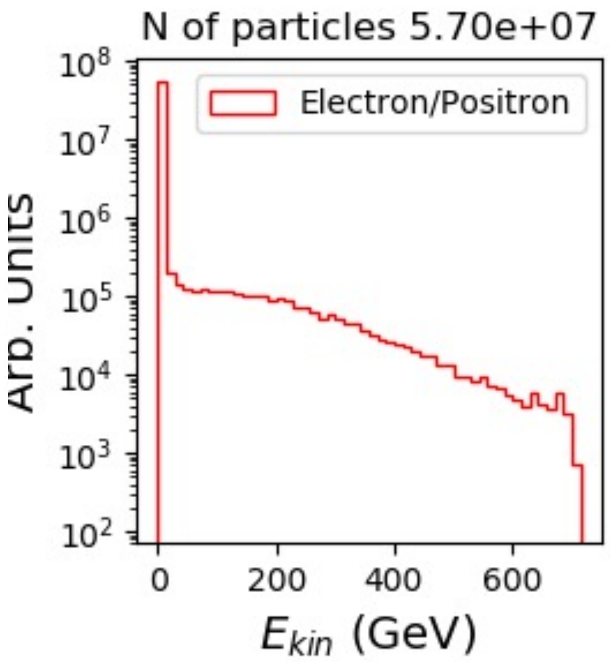
Beam-Induced Background in the detector with the FLUKA simulation



[Advanced assessment of Beam Induced Background at a Muon Collider](#) on arxiv

Can we remove the nozzle?

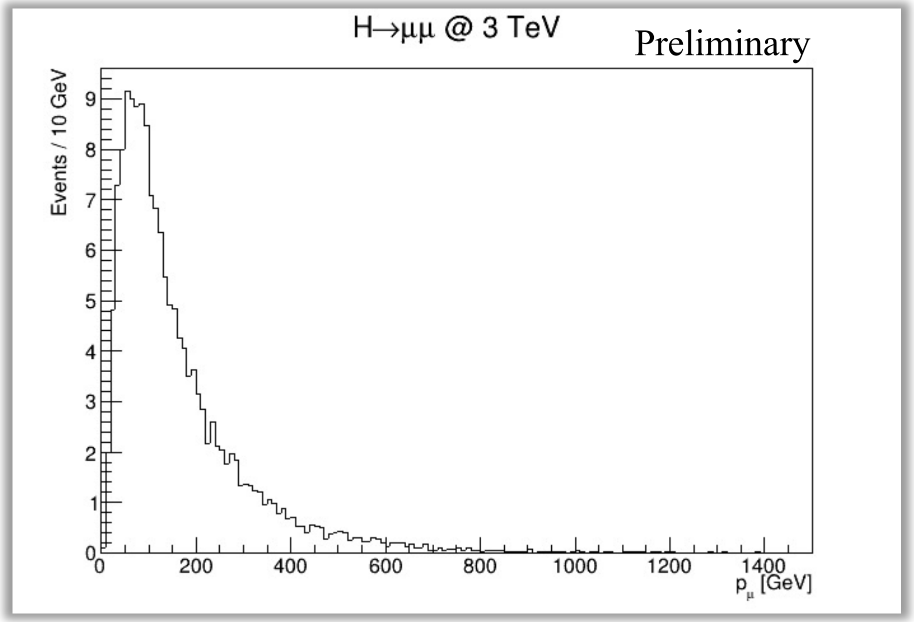




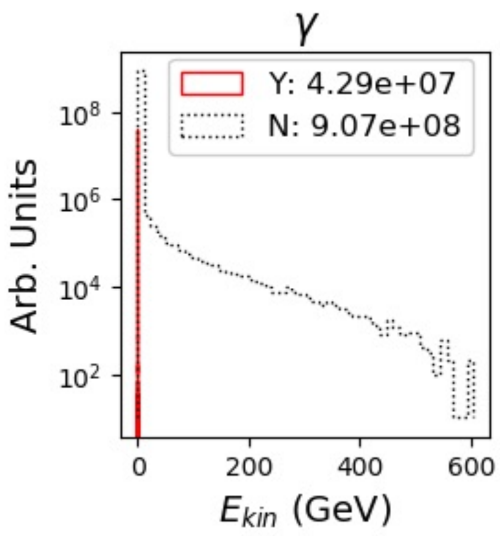
Energy spectrum of Photons and e^+/e^- arriving in the detector hall with no nozzle per beam-crossing, one beam only at $\sqrt{s}$ =1.5 TeV

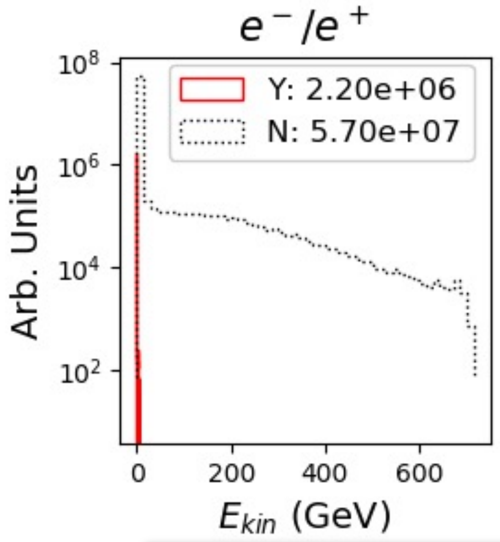
$$\mu^+\mu^- \rightarrow H + X \rightarrow \mu^+\mu^- + X$$

A. Montella

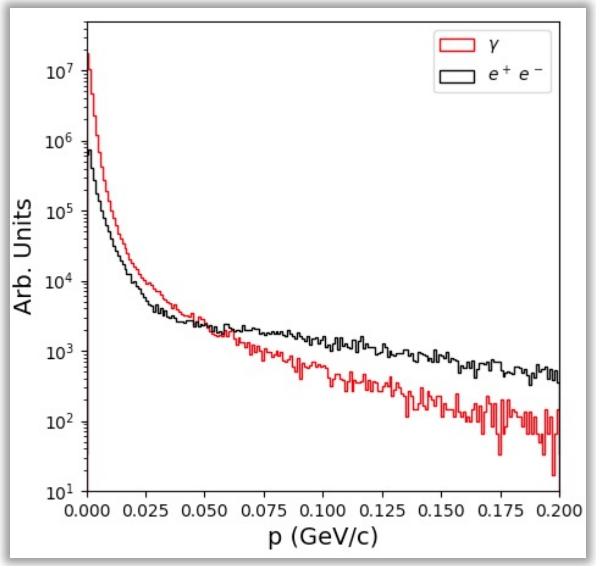


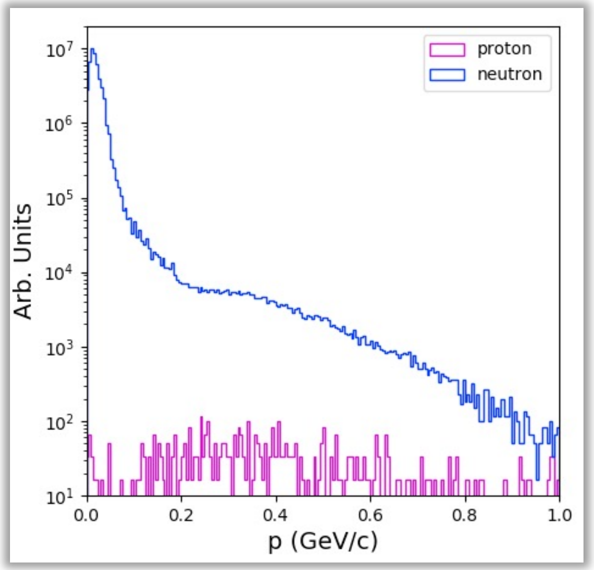
Beam-Induced Background Characteristics with Nozzle at $\sqrt{s}$ =1.5 TeV

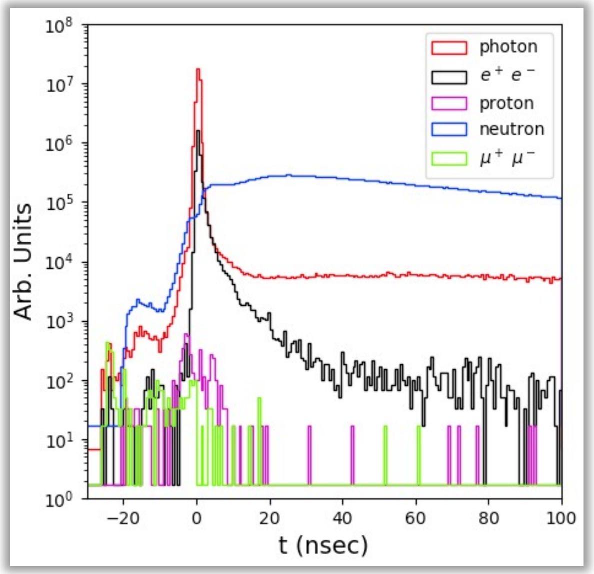




Nozzle remove the high momentum component





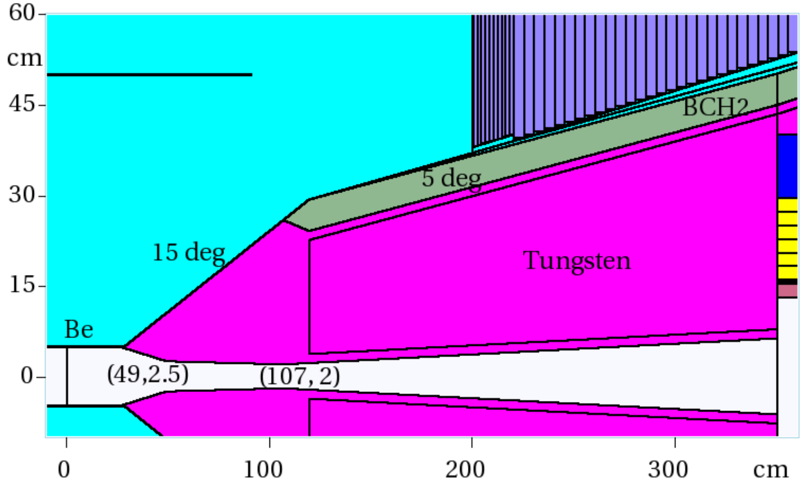


Beam-Induced Background at Different Center-of-Mass Energies

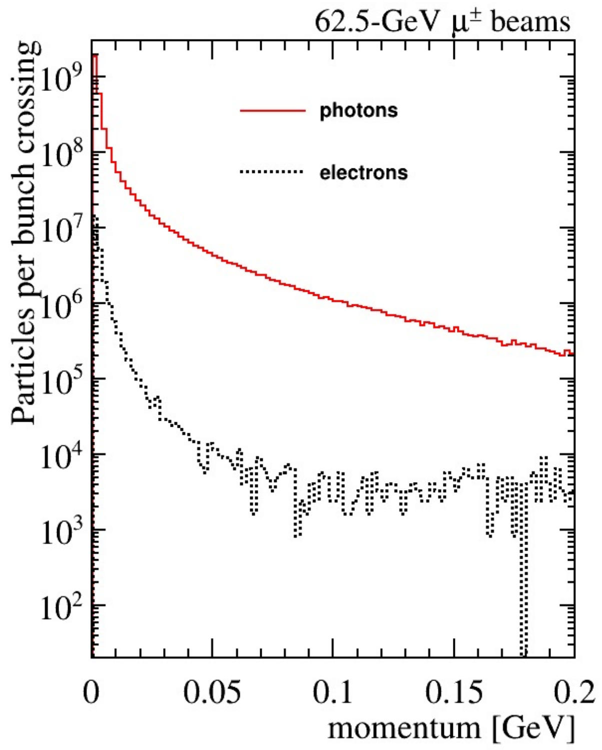
Beam-Induced Background Characteristics at $\sqrt{s} = 125$ GeV

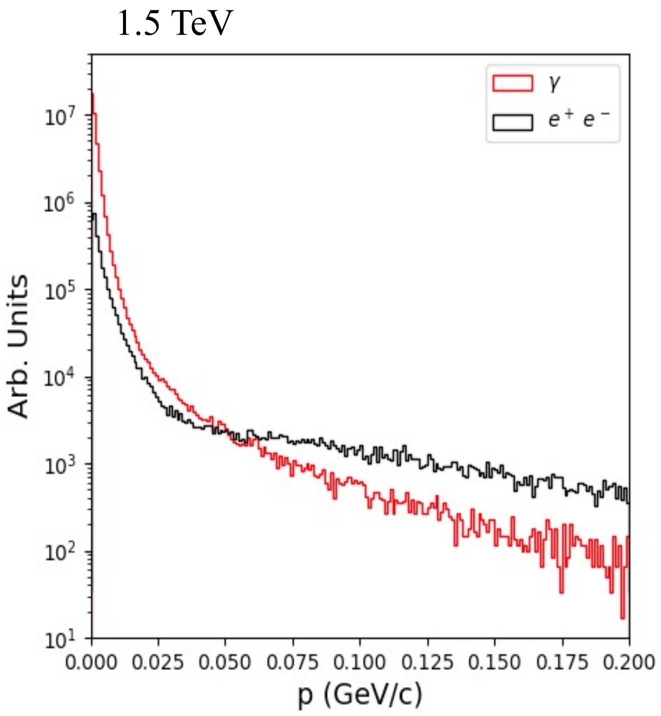
S.I. Striganov et al. *Reducing Backgrounds in the Higgs Factory Muon Collider Detector* Fermilab-Conf-14-184-APC TUPRO029, and Proc. IPAC2014, Dresden, Germany, June 2014, p.1084

N. Bartosik et al. *Preliminary Report on the Study of Beam-Induced Background Effects at a Muon Collider* arXiv:1905.03725

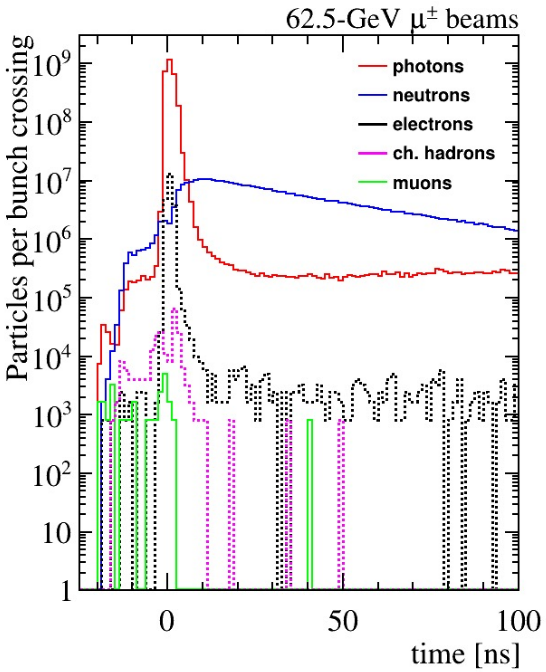


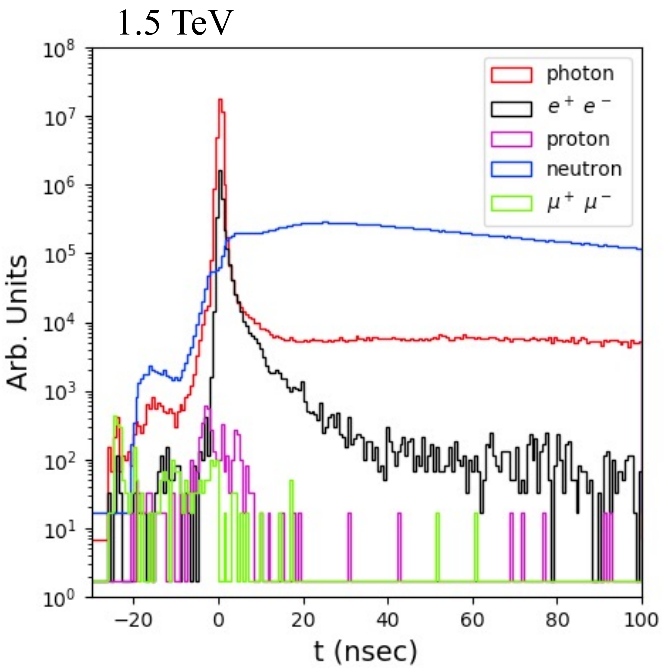
beam energy [GeV]	62.5	750
μ decay length [m]	3.9×10^5	4.7×10^6
μ decays/m per beam	5.1×10^6	4.3×10^5
photons ($E^{kin}_{\text{ph.}} > 0.2$ MeV)	3.4×10^8	1.6×10^8
neutrons ($E^{kin}_{\text{n}} > 0.1$ MeV)	4.6×10^7	4.8×10^7
electrons ($E^{kin}_{\text{el.}} > 0.2$ MeV)	2.6×10^6	1.5×10^6
charged hadrons ($E^{kin}_{\text{ch.had.}} > 1$ MeV)	2.2×10^4	6.2×10^4
muons ($E^{kin}_{\text{mu.}} > 1$ MeV)	2.5×10^3	2.7×10^3

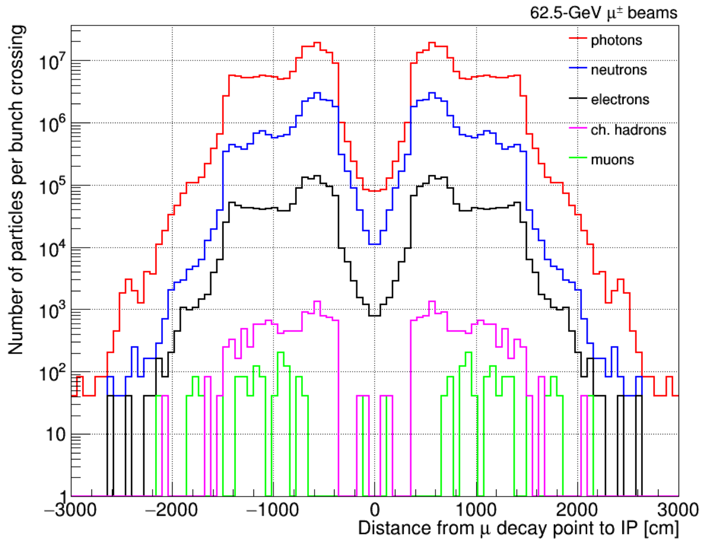


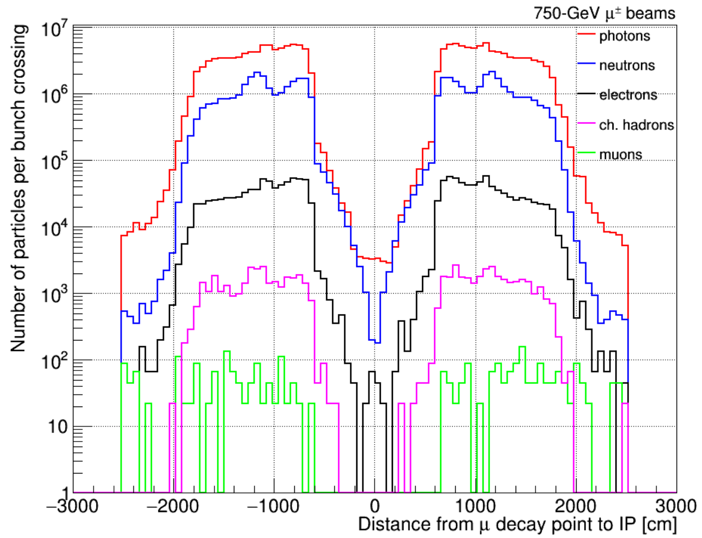


Beam-Induced Background Characteristics at $\sqrt{s}$ = 125 GeV









Comparison between $\sqrt{s}$ =1.5 TeV and $\sqrt{s}$ = 125 GeV

- BIB absolute fluxes very similar
- Momentum distribution quite different
- Time distribution as expected and Z distribution very similar

In effect, the IR has been designed to obtain that!

Would be possible to do the same for high energy?

Given the BIB, how do we design the detector?

Is it competitive with the respect to other colliders?

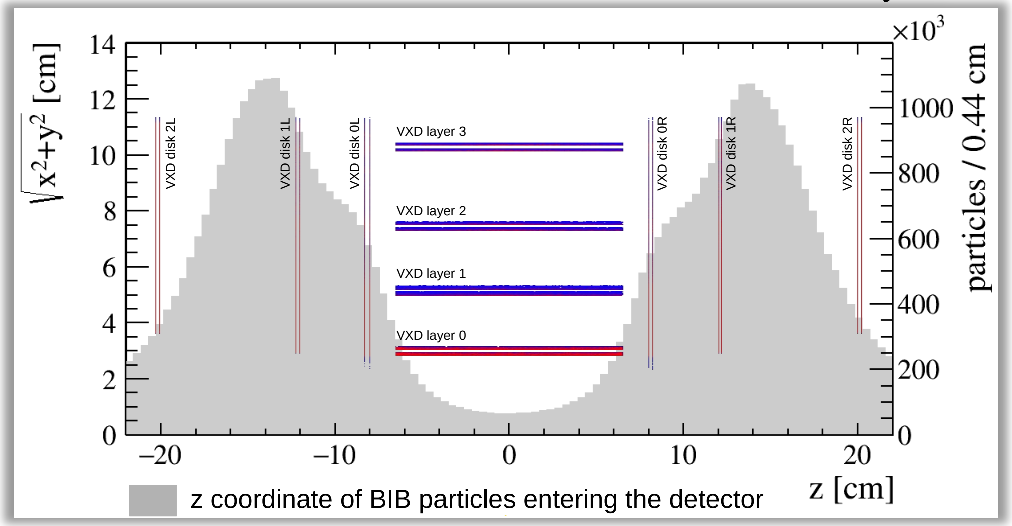
Two examples:

- Tracking and muon
- Calorimeter

Electron and photon reconstruction in progress

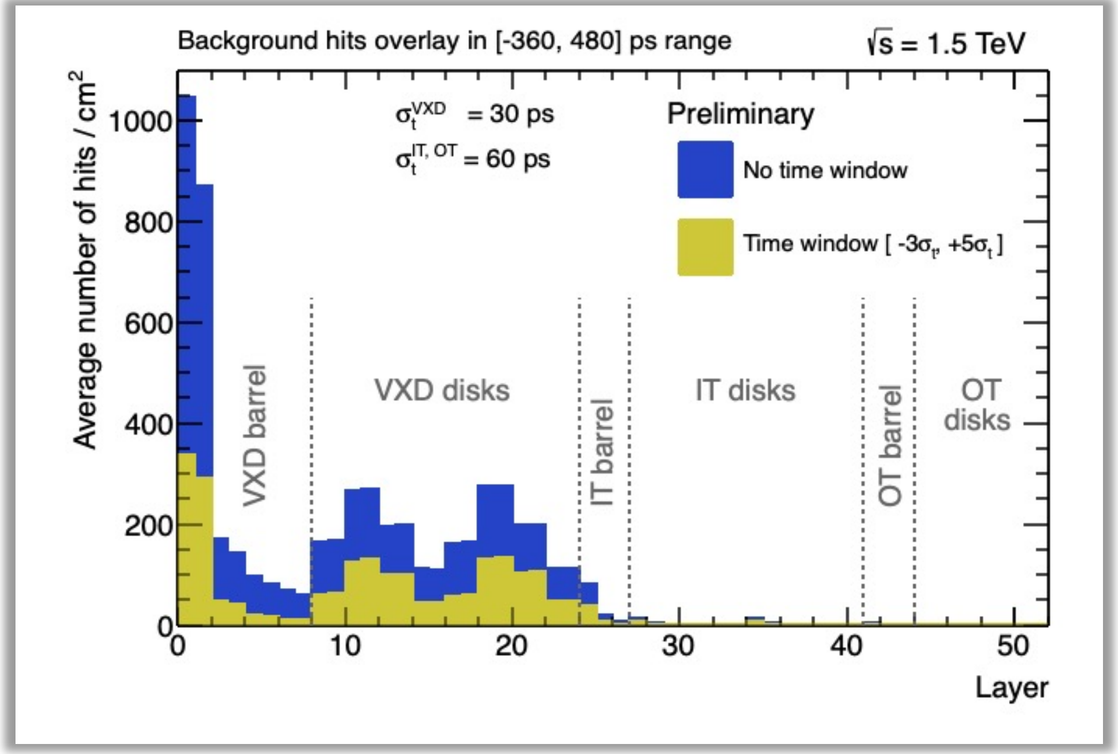
Tracker at $\sqrt{s}$ =1.5 TeV

Preliminary



Vertex detector properly designed to not overlap with the BIB hottest spots around the interaction region.

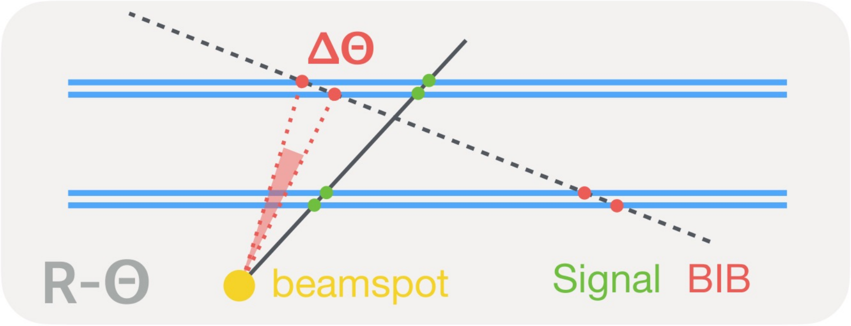
Preliminary



Tracking performance have been studied applying timing and energy cuts on clusters reconstruction compatible with IP time spread.

Tracking at $\sqrt{s}$ =1.5 TeV

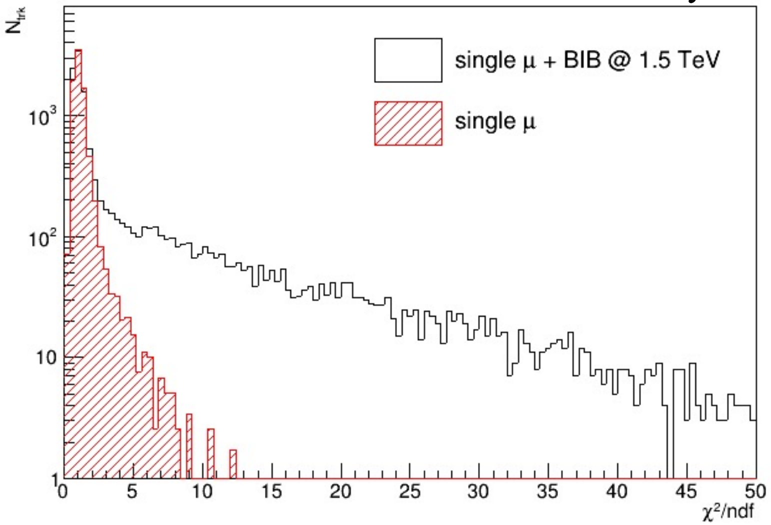
N. Bartosik



- BIB particles not coming from primary vertex
- Double layer structure can be exploited correlate hit pairs on adjacent sensors to estimate incoming particle direction.

In the future, remove hits at data taking time?
Does it bias short-lived or long-lived particle reconstruction?

Preliminary



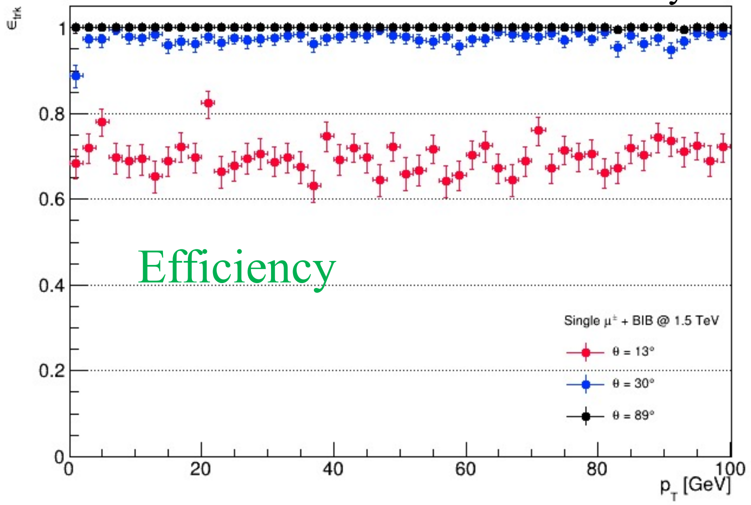
Tracking strategy

- Use region of interest: muon and jets up to now
- Muon: reconstruct a muon stub using the muon detector, define a cone around it and use only these hits

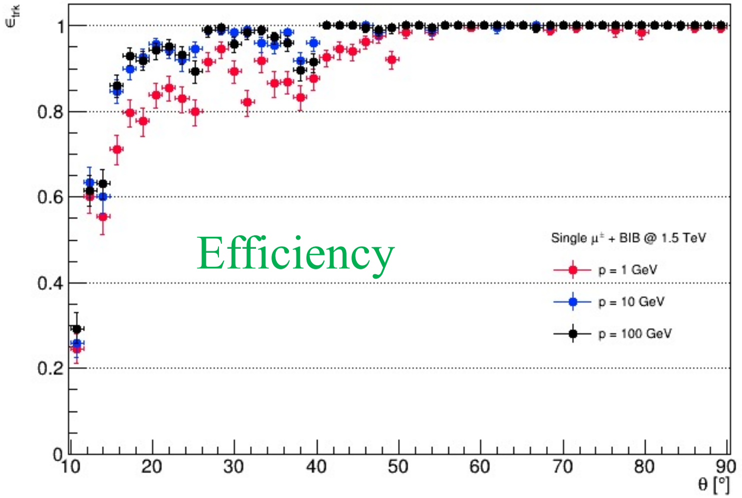
Tracking Performance at $\sqrt{s}$ =1.5 TeV

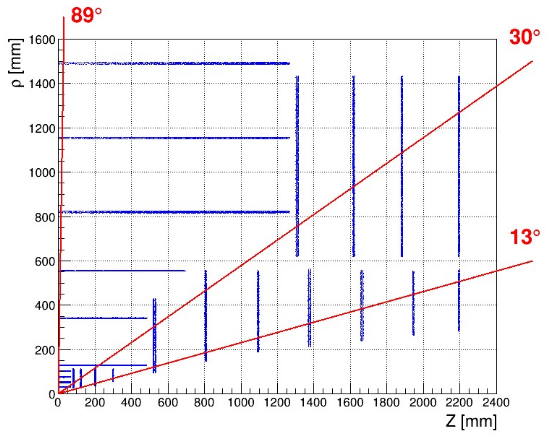
M. Casarsa

Preliminary



Preliminary

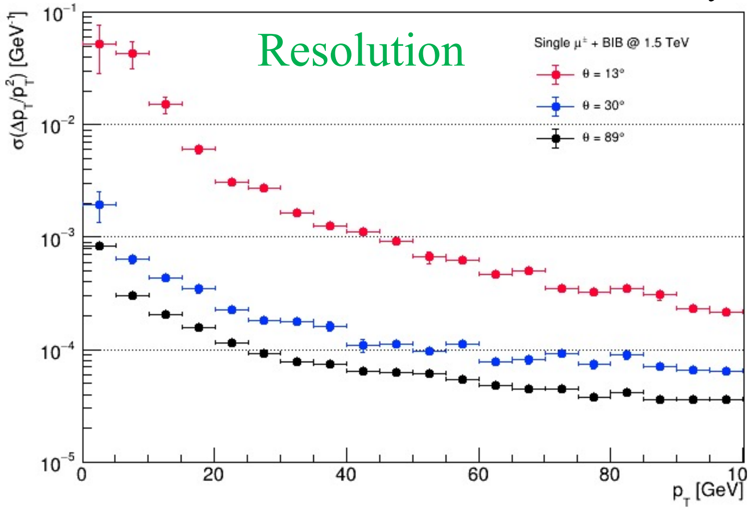




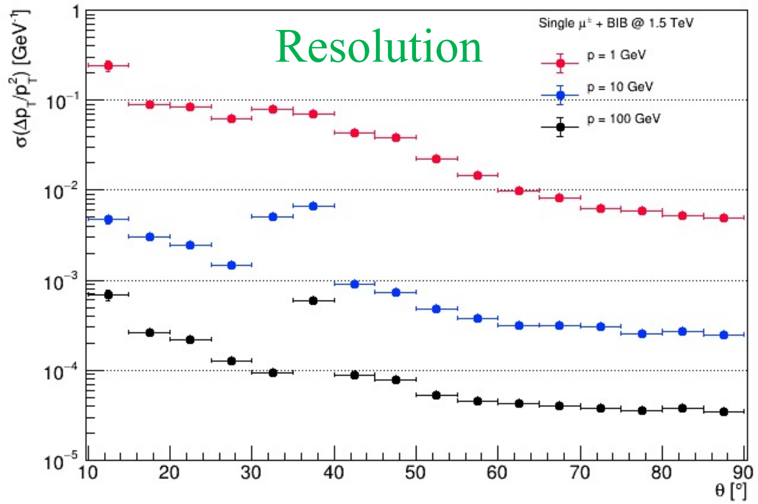
In the nozzle region:

- Efficiency drops
- Momentum resolution degrades

Preliminary

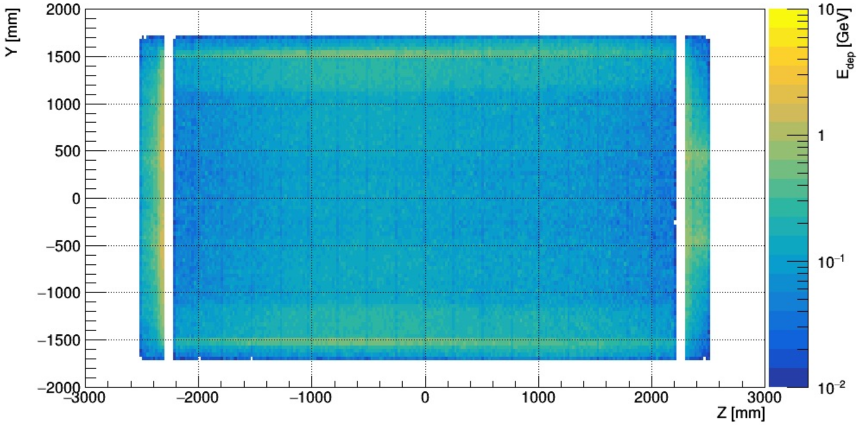


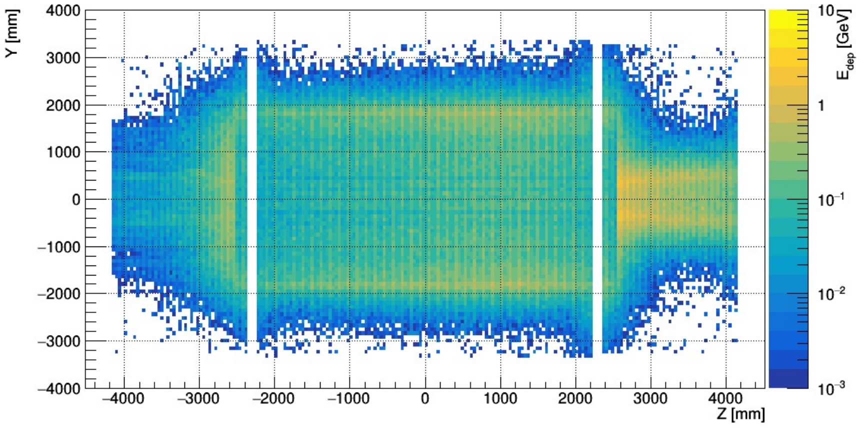
Preliminary



Dedicated tracking detector/algorithm needed

Calorimeter at $\sqrt{s}$ =1.5 TeV

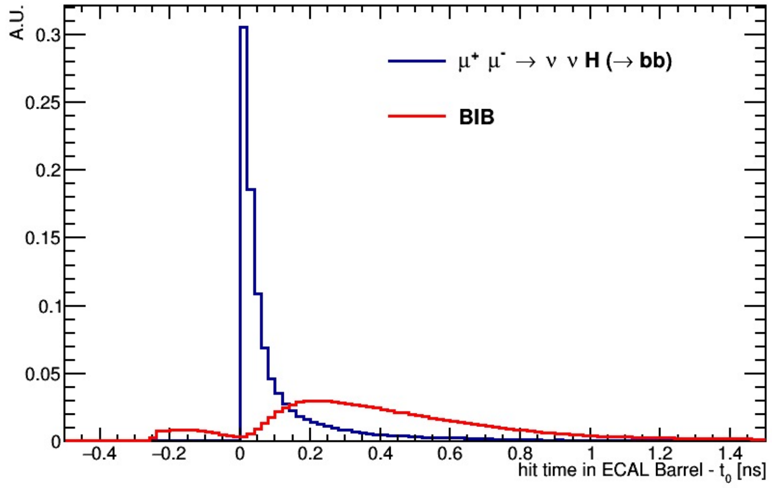




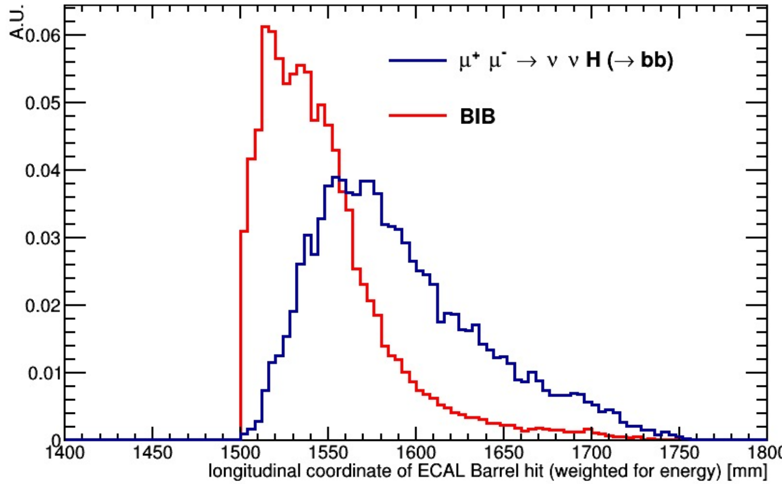
BIB deposits large amount of energy in both ECAL and HCAL

Timing and shower profile should be used in clusters reconstructions

ECAL barrel hit arrival time – t_0



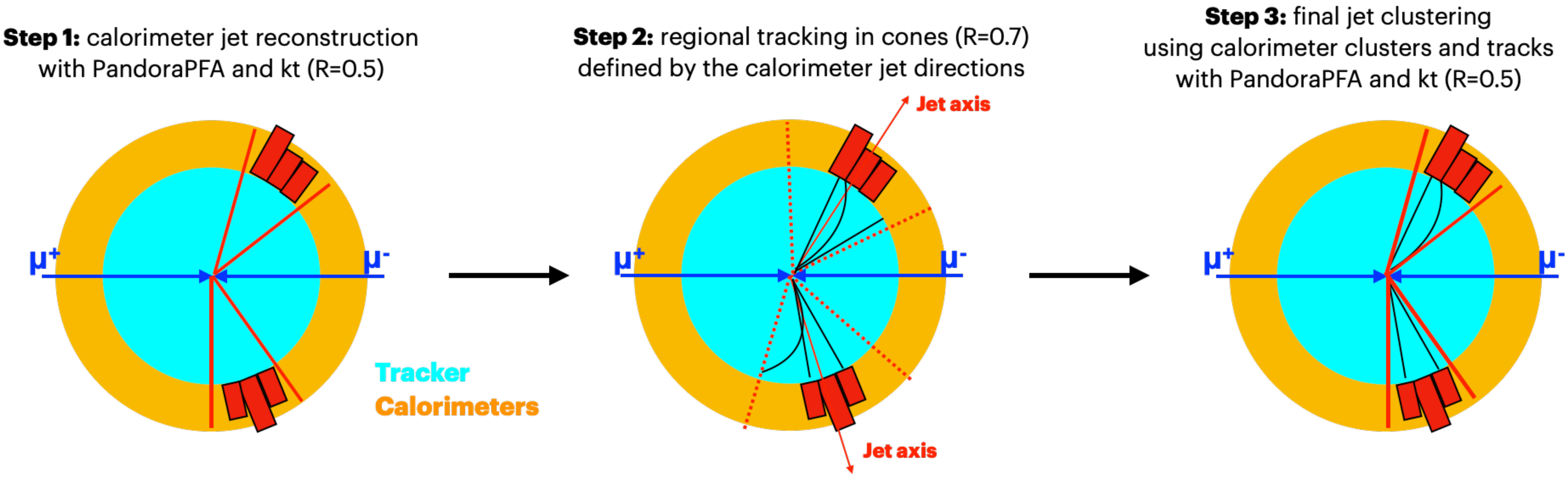
ECAL barrel longitudinal coordinate



Jets Reconstruction at $\sqrt{s}$ =1.5 TeV

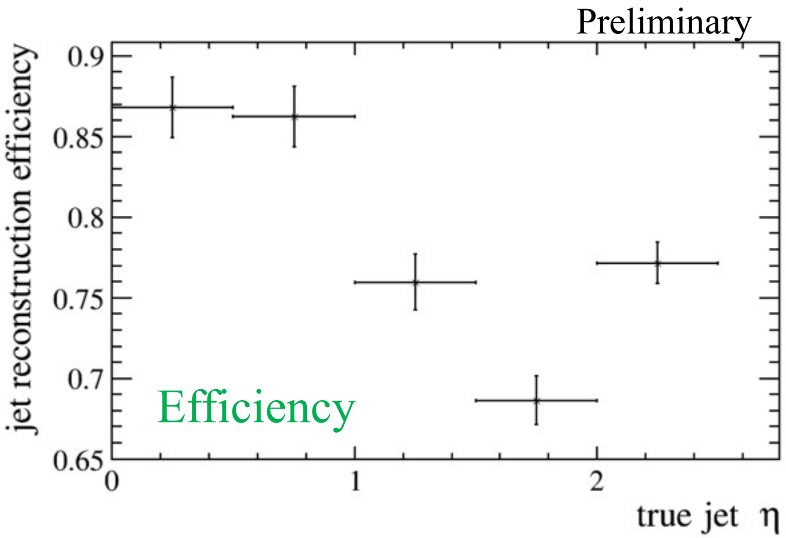
L. Sestini

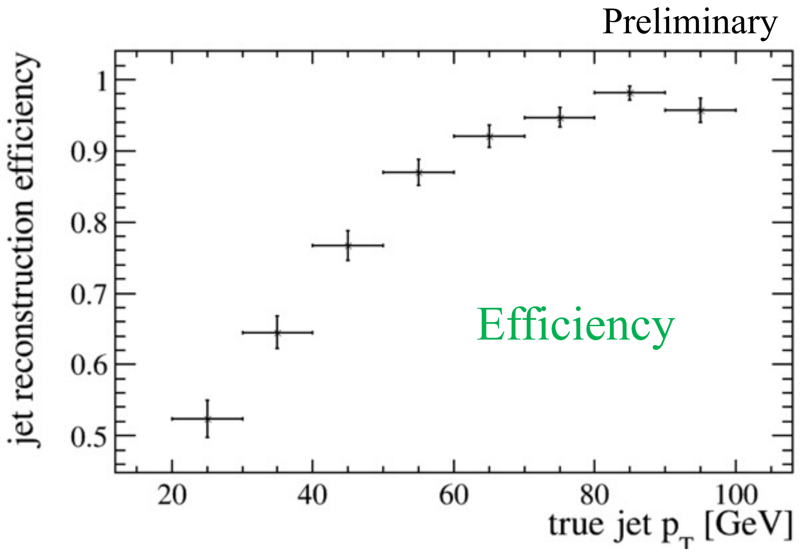
- Data samples: inclusive b, c and light di-jet generated with Pythia8 in six p_T bins: [0,40], [40,80], [80,120], [120,160], [160,200], [200,∞] GeV
- 30 BIB beam-crossings used in turn to obtain di-jets+BIB
- Before reconstruction, BIB subtraction in ECAL barrel applied. ECAL endcaps are not used
- HCAL barrel and endcaps no BIB subtraction



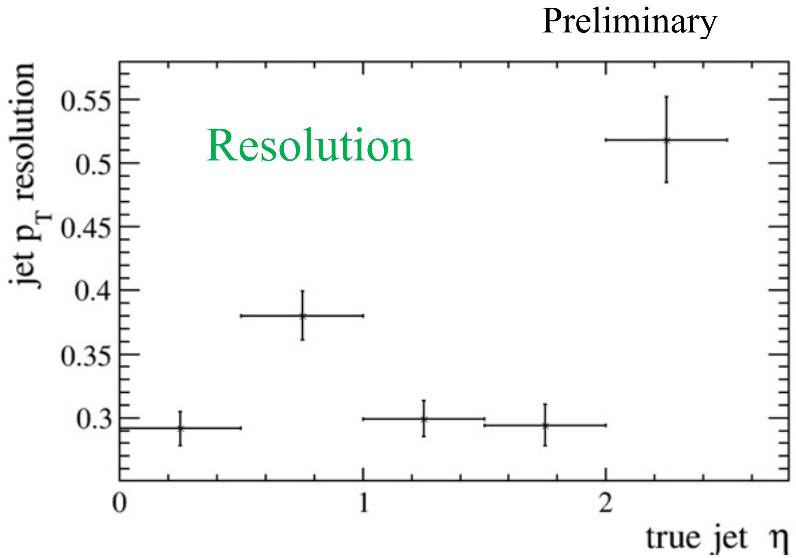
Jets Reconstruction Performance at $\sqrt{s}$ =1.5 TeV

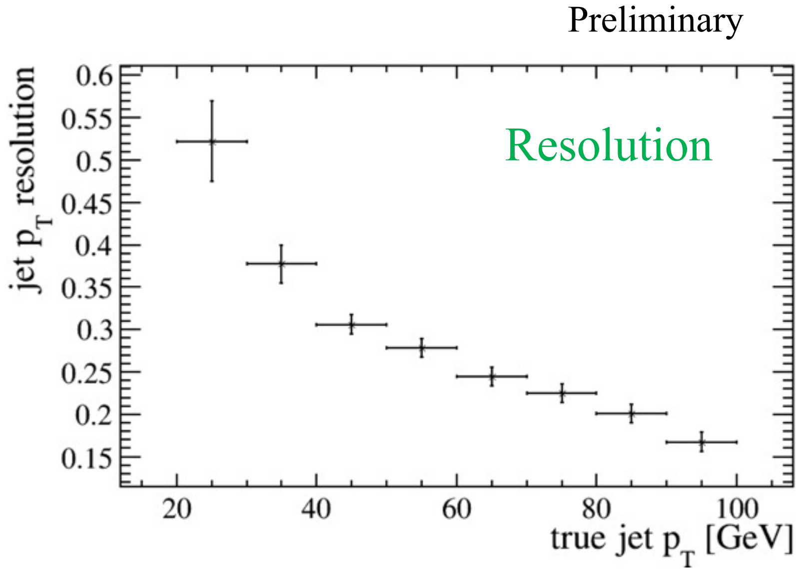
L. Sestini





Good b-jet reconstruction efficiency at high momentum and in the central region

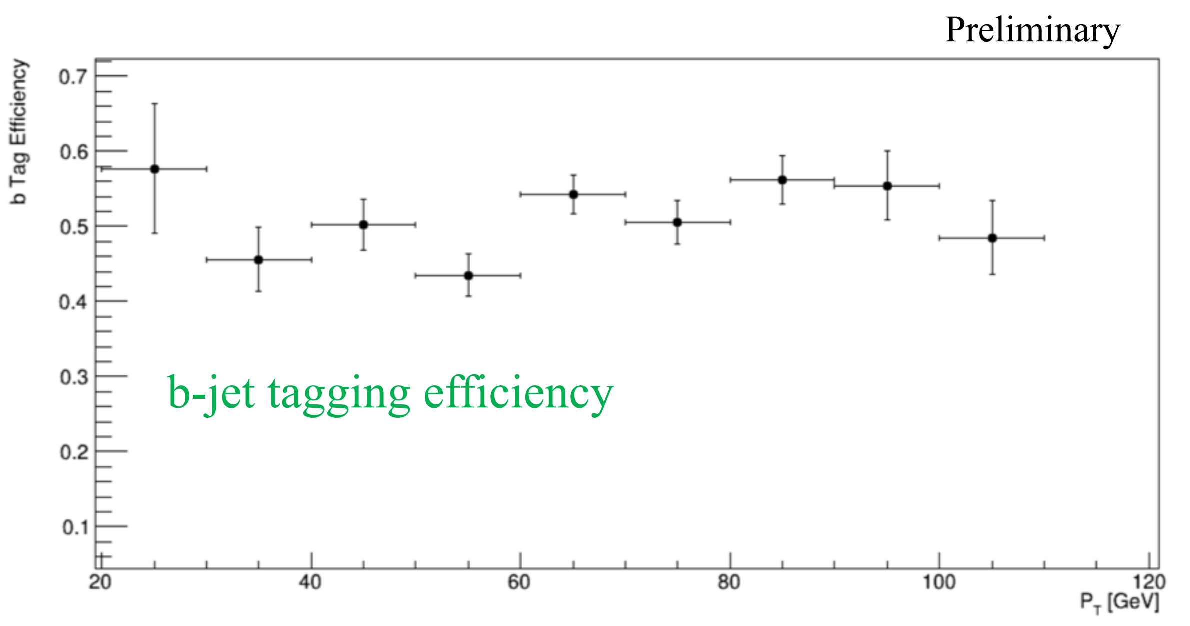


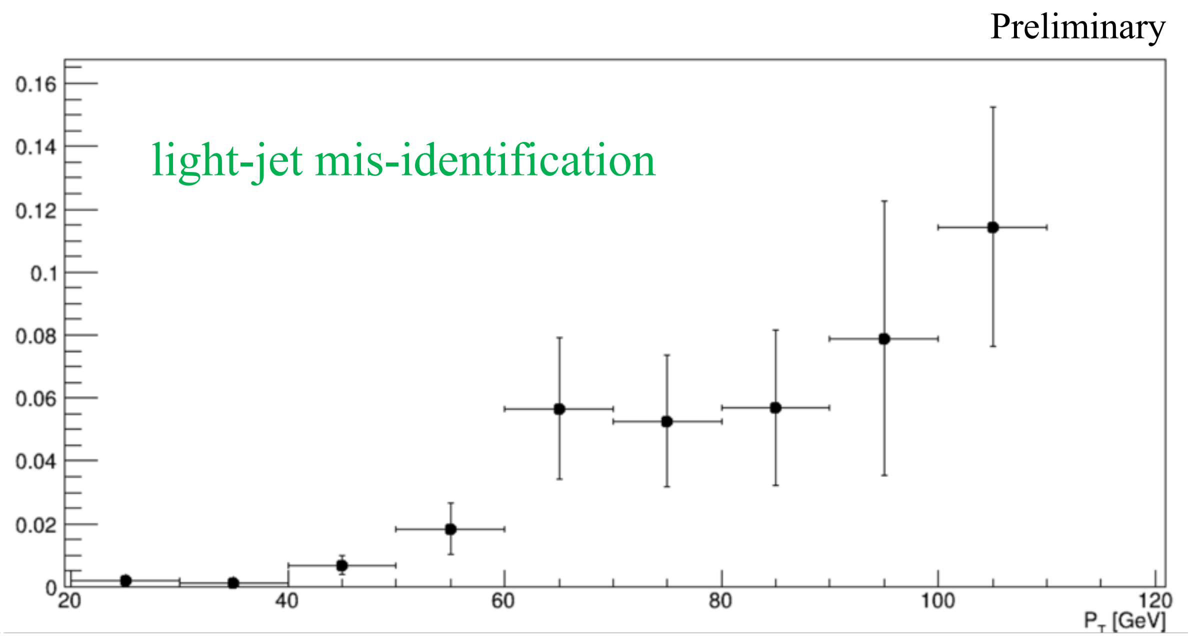


Jet energy correction depends on η and p_T
Degradation of the resolution in the nozzle region

b-jets Secondary Vertex Reconstruction at $\sqrt{s}$ =1.5 TeV

L. Sestini, L. Buonincontri



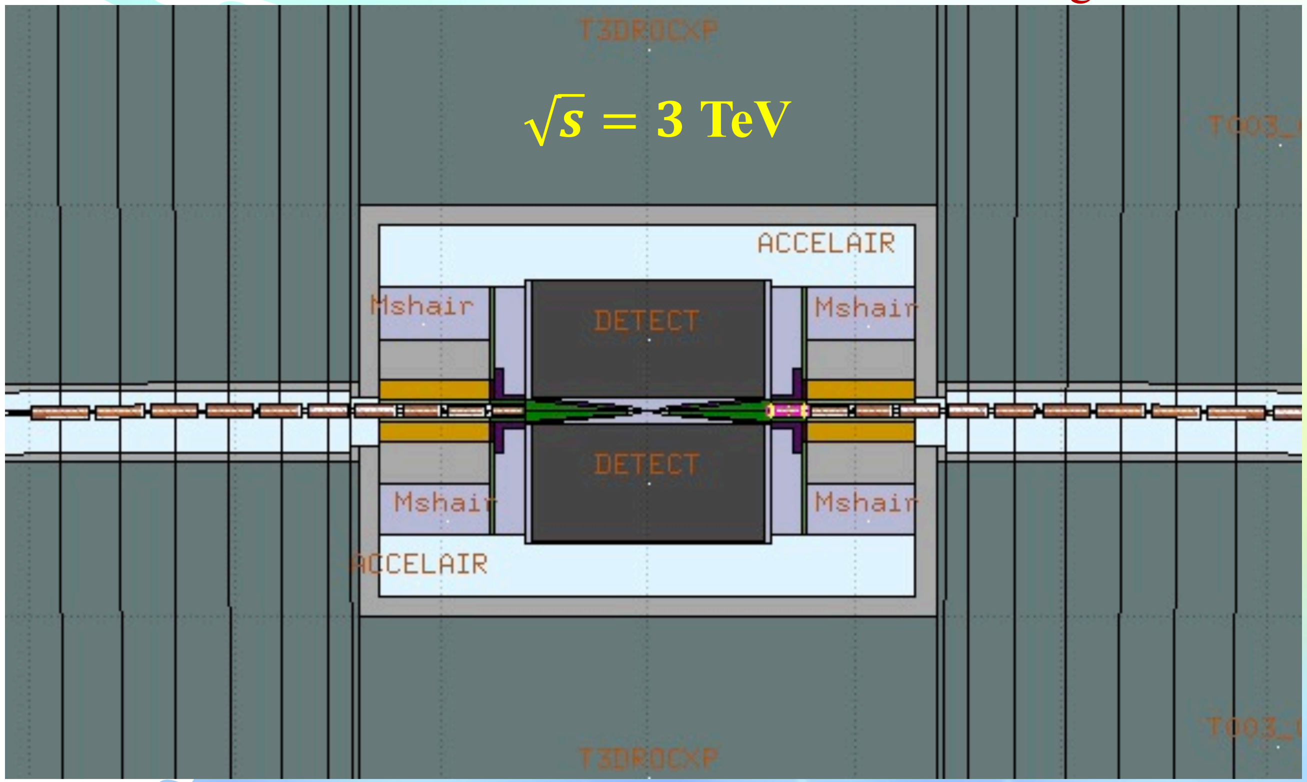


b-jet identification

- Tracks selected by the regional tracking
- Secondary vertex requested to be inside the jet cone
- First step toward a b-jet tagging, under development a ML-based algorithm

A. Mereghetti

Summary



- ✓ Tool to produce beam-induced background is ready provided the IR design
- ✓ BIB study at $\sqrt{s}$ =1.5 TeV at $\sqrt{s}$ = 125 GeV shows similar behavior.
- ✓ The $\sqrt{s}$ = 3 TeV BIB study is starting!

- Detector studies are just at the first step, a lot of room for improvements!
- Physics objects performance are very good even if not optimize, room for improvements in particular with ML techniques
- Dedicated studies and optimization is needed for the forward region, covered by the nozzle